# FIFTH ANNUAL INTERNATIONAL WORKSHOP

# ON

# HUMAN SUBJECTS FOR BIOMECHANICAL RESEARCH

## Minutes of Fifth Annual Meeting and Technical Session

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The Fifth International Workshop on Human Subjects for Biomechanical Research was convened by the Chairman at 9:00 a.m., on October 18, 1977, at the Hotel Monteleone in New Orleans, Louisiana. More than 75 persons attended this workshop. Mr. Hirsch opened the meeting by noting that the mailing list was once again out of date, and be requested that all in attendance provide their current address on forms available at the meeting. He also again stressed the informal nature of the Workshop and cautioned attendees not to consider the proceedings of the meeting and technical session as "publications" to be used as "references." (If participants wish to reference their technical session presentations, they should assign internal report numbers to them and reference those reports.)

COMMITTEE REPORTS

1. Ad-Hoc Committee on Injury Scaling

Dr. John W. Melvin, HSRI, Coordinator for U. S. Activities
Dr. Claude H. Tarriere, Peugeot-Renault, Coordinator for Overseas Activities

Dr. Melvin discussed several areas of progress during the year. Dr. D. L. Berens, SONY at Buffalo, is preparing a summary of x-ray analysis techniques. Dr. Robert Levine, Wayne State University, and Dr. John States, Rochester General Hospital, are developing scaling guidelines for the pelvis and lower extremities. Since injuries to the tibia, femur, knee and pelvis can cause serious impairment but are seldon involved in fatalities, the subcommittee will consider including impairment in the scale. They will have a more detailed report at the next workshop.

Dr. Tarriere, Dr. Melvin and Mr. Hirsch then discussed a recent workshop on head and neck injury which had been sponsored by the National Highway Traffic Safety Administration (NHTSA). Attendees included research neurosurgeons, research pathologists, engineers and others who were actively studying head injury. The workshop had two principal objectives.

a. Establish a standardized set of autopsy procedures which will identify all significant lesions. The intent is to devise common procedures and nomenclature, with the future objective of computer retrieval of autopsy data for statistical analysis. Two current activities on this topic are preparation of autopsy protocols and efforts to describe, locate and quantify lesions for computer access.

b. Assess the cadaver as an appropriate surrogate for brain injury. The intent is to test the hypothesis that impacts to cadavers may produce identifiable brain lesions which can be correlated to post-trauma conditions observed in living persons. The consensus of the head injury workshop was that there were no readily-identifiable lesions which would correlate well. It was recommended that investigators continue to search for lesions which could be correlated to injuries. Two hospitals currently have research programs comparing data from three-dimensional serial CATSCANS to injuries as described in patient histories.

Dr. Tarriere then described some of the work underway in Europe to address the problem of standardized autopsy protocol. There are now five or six teams working with the anatomical coordinates recommended by the ad-hoc committee of this workshop; they are also using a common autopsy protocol. Dr. Tarriere had some detailed comments on two recently suggested autopsy protocols, one from Schmidt and one from Itabashi and Smith. He first noted that the European community feels it is important that injury scaling differentiate between primary (directly related to the impact) and secondary (induced, not directly related to impact) injury categories. He also noted the importance of linking the lesion to the injury mechanism.

Dr. Tarriere then made specific comments about proposed items in the three minimal requirements for classification -- the site, the nature, and the intensit of injuries. For the broad classification of injury site, he feels the catetory of "external landmarks" is unnecessary for brain injuries (except for cranial nerve and spinal nerve root injuries), since external conditions are always a manifestation of internal injury. Brain stem injuries need to be defined and included. Also, he feels that skull, facial bone and tissue, and neck injuries should be included in the same classification system so that brain injuries can be related to other injuries outside the brain.

The nature of brain lesions should involve three categories in Dr. Tarriere's opinion. At the first level are injuries directly attributable to the energy input or the severity of the blow. Next are injuries which are directly related to the blow but not proportional to its severity. Third are lesions due to "indirect consequences -- "for example, emboli. In the category of injury intensity, Dr. Tarriere agreed with the proposal that intensity should be quantified. He mentioned volume of "hemorrhage" as an example.

Dr. Tarriere concluded his remarks by stating that the proposals form a good working basis. He advocates further work to develop an international consensual agreement on head/neck injury classifications and autopsy protocol.

Dr. Carley C. Ward, U. S. Navy Civil Engineering Laboratory, described her current project of developing a common set of lesion descriptions that could be used in computerized data banks. She is developing a simplified format based on injury types, anatomical locators, and severity descriptors. She has solicited and received suggestions from several researchers. She also noted, in response to a comment, that the data bank will be constructed to permit detailed analysis. More general analyses can be automatically created by build-in techniques to summarize detailed classifications into more general categories.

Mr. Hirsch concluded the discussion on injury scaling by announcing that a proposed protocol for head and neck dissection will soon be distributed to the research community for review, possibly by the end of 1977.

2. Ad-Hoc Committee on Guidelines for Comparison of Human and Human Analog Subjects

Dr. Daniel J. Thomas, NAMRL, Chairman

The ad-hoc committee made no formal report to the workshop at this meeting. However, Mr. Hirsch did note that Dr. Guinard of the U. S. NAMRL, Chairman of a working group in the International Standards Organization (ISO) is using the ad-hoc committee's recommended anatomical coordinate system and is interested in its adoption as an international standard.

3. Ad-Hoc Committee on a Statement of Ethics

Dr. Richard G. Snyder, HSRI, Chairman

This committee completed its work in 1975. Dr. Snyder reviewed the committee's work and gave some followup information. He reminded workshop attendees of the existence of the Code of Ethics and encouraged researchers to include the statement in their publications. The statement was adopted in 1975 by resolution of the American Association of Physical Anthropologists and has also been approved by the CHABA committee of the National Academy of Sciences. A copy of the NAS resolution has been included with these proceedings as a convenience to workshop attendees.

## TECHNICAL SESSION

Following the committee reports, a technical session was held in which seventeen informal papers were presented under the general topics of cadaver utilization and test instrumentation. Brief descriptions of each paper are contained in this section of the minutes, and more details of many of the presentations are in the papers that are included with the proceedings.

### CADAVER UTILIZATION

1. Artifacts Encountered in Cadaver Vascular Pressurization Experiments, Dr. Randall W. Smith, University of California at San Diego.

Dr. Smith reviewed three problems he and Dr. Nahum have encountered in creating a "marker" for detecting brain trauma in cadavers. In their UCSD research program, they are pressurizing the brain vascular system and are using ruptures of the blood vessels, as indicated by extravasation of India ink solution, as the marker.

The chief problem is one of imperfect perfusion. Because of the complexity of the Circle of Willis, they find that the pressurized fluid, which is injected through the carotid arteries, does not completely perfuse the brain vasculature. Occasionally, the fluid shunts through the Circle of Willis in such a way that only one hemisphere is perfused. Of course, trauma marked by extravasation cannot be detected if the trauma site is not perfused, so Dr. Smith's team is developing better perfusion methods.

Another problem was encountered in trying to solve the incomplete perfusion problem. They tried to detect damage in non-perfused tissues by perfusing the brain directly through the base of the Circle of Willis immediately post-test. They discovered that this approach created artifacts in the brain stem by rupturing the fine cerebellar vessels. They concluded that post-test external pressurization was unreliable as an indicator of trauma. Dr. Smith and Dr. Nahum have also concluded that pressurizing through arteries in the neck is the preferred method since, even though complete perfusion may not be achieved, the extravasation that occurs is not artifactual.

Subject selection highlighted the third problem reported by Dr. Smith. He has discovered that subjects who were stroke patients before death cannot be perfused. Extravasation of the marker fluid occurs before test due to the pre-existing diseased state of the brain vasculature and rupturing of small blood vessels.

2. Some Deficiencies of the Cadaver Model in Biomechanical Research, Dr. J. J. Vostal and Dr. D. C. Viane, General Motors Research Laboratories.

Dr. Vostal indicated that some direct comparison tests of living and cadaver porcine subjects have been conducted to determine if cadaver subjects provide reliable indicators of life-threatening trauma.

Dr. Viano described the experiments, which consisted of thoracic impacts. It has been noted that anesthetized live subjects always exhibited some myocardial dysfunction as evidenced by post-impact electrocardiogram. However, these dysfunctions are not well correlated with autopsy results. This finding indicated that life-threatening myocardial problems are not reliably detected in tests with cadavers. They also found that commonly-used measures of response are not always well correlated with myocardial problems in the living subject. The best correlation of this type was between sternal acceleration and post-impact fibrillation. In comparing aortic overpressures, Dr. Viano found that porcine cadavers that had been repressurized to normal blood pressure exibited responses that were three to seven times those of anesthetized live subjects. He noted the chief problems with using cadavers in thoracic impact tests: poor assessment of potential life-threatening injuries; artifacts due to repressurization of the vasculature; non-comparable impact response; and dissimilarities in kinematic response.

Dr. Viano was asked about the possible effects of anethesia in his live subjects. He noted that effects due to specific types of anesthesia were not found, since four types of anesthetic drugs were used and no response differences were detected. Dr. Tarriere mentioned that his comparison tests with animal subjects had shown that cadavers were good indicators of brain lesions.

Dr. Melvin noted that the volume of fluid used to repressurize the cadaver should be controlled, not just the pressure, so that the vascular system is not overfilled. He also mentioned that, due to cadaver storage methods, the core temperature may be cold at the time of test and this could affect vascular response. Dr. Viano was then asked if porcine subjects are more susceptible to shock and trauma in the thoracic region than are humans. He responded that comparisons with clinical observations of humans in emergency rooms lead him to believe that porcine subjects are resonable close in response. In any event, the existence of fibrillation is not detectable at autopsy. Clinicians have also conducted that porcine hearts are good analogs to human hearts.

3. An Effective Surrogate for Impact Studies, Dr. D. L. Bernes, State University of New York at Buffalo.

Dr. Berens, a radiologist, has examined 19 cadavers post-impact and 146 persons (drivers, passengers, pedestrians and bikers) who were dead on arrival at the emergency room. He used the same radiological examination techniques for each group and has noted some similarities between the post-test cadaver x-rays and the injuries received in accidents. He feels the radiologist can help the forensic pathologist determine where to look for lesions, especially those high in the neck and in the skull. He also noted other examples where x-rays may indicate other trauma and the force of impact: fractures of the clavicle, first rib or second rib can injure the brachial plexus; fractures of a transverse process of the first or second lumbar vertebrae can lacerate the liver and spleen; fractures of the first and second ribs or posterior rib fractures indicate higher energy levels at impact than do anterior or lateral rib fractures or fractures of lower ribs; and ruptures of the gut, the lungs, other hollow organs, liver and kidneys caused by blunt truma may be detected even though there is no external penetration. Dr. Berens feels it is more important to examine x-rays for air in the wrong places., organ shifts, and hemorrhages than to count broken ribs (which are, in general, clinically unimportant). He also observed that pneumothorax can occur without rib fracture, and that preventing rib fracture will diminish but will not eliminate either pneumothorax or cardiac arrythmia.

4. A Simplified Method of Attaching Accleromoter Packages to Bone, Dr. Robert Levine, Wayne State University.

Dr. Levine, an orthopedic surgeon, briefly reviewed a technique he has developed which creates a solid instrumentation mount on the spine without the necessity of dissecting to expose the vertebrae. He inserts threaded or unthreaded stainless steel Steinmann pins in the spinous processes or laminea of the vertebrae. X-ray markers and x-ray control are used to locate and place the pins. Dr. Levine reported that the technique holds well, is applicable to any part of the body, and presents no operational problems for the externally mounted instrumentation. Stress risers in the bone tissue are minimized by careful selection of pin size. Bending of the mounting pins is not a problem if pins of adequate cross-section are used.

5. Vascular and Respiratory Pressurization of the Thorax, Guy S. Nuscholtz, Highway Safety Research Institute.

HSRI is conducting an extensive series of thoracic impact tests with cadavers, and Mr. Nuschaltz reviewed the procedure and techniques used to pressurize the thorax of the test subjects. The vascular system is pressurized with fluid introduced through a modified Foley catheter inserted in the carotid arteries. Since impact acceleration can cause leaks at the insertion, the carotids are sealed by tying them against a soft plastic pluc which is inserted into the artery. The thoracic vasculature is isolated by means of an aortic balloon placed at the level of the diaphragm. The respiratory system is pressurized through the trachea. The pressurization tube is sealed tightly with a tape wrap and is checked for leaks with pressurized air.

At the time of test, the cadaver is placed in seated position on a free-sliding seat. After positioning the cadaver for the test, the vascular system is repressurized by introducing pressurized air into a partly fluid-filled bottle. When the desired vascular pressure is achieved, the bottle is sealed. Immediately before the impactor sequence is begun, the lungs are pressurized to 15 mm of mercury. Impact force is applied when a pendulum strikes the piston impactor. Post-test, the cadaver is removed from the test device using paramedic-type extraction techniques to minimize further tissue damage.

Mr. Nuscholtz remarked that x-rays are taken before the test but not after. Dr. Berens observed that post-test x-rays would be useful in identifying any pneumothorax resulting from the impact.

6. Nine Accelerometers and Brain Motion Detection, Dr. Richard Stalnaker, HSRI.

Dr. Stalnaker feels that a nine-accelerometer system, rigidly attached to the skull in a fixed coordinate system, is a valuable method of quantifying the usefullness of a given cadaver. Comparisons of linear and angular acceleration responses have revealed the effects of differing brain conditions. If the brain is stiff it tracks the motion of the skull; if soft and uncoupled from the skull, inertial effects of the brain tissue allow the skull to move relative to the brain. Dr. Stalnaker feels this technique can be used to detect differences in brain tissue which are related to time after death or to pressurization. He determined that, after four days postmortem, the brain degenerates and does not adequately reflect the in vivo state. At this point, pressurization of brain vasculature is unlikely to produce useful results. Dr. Stalnaker advocated using this nine-accelerometer technique to establish a matrix from which brain condition could be estimated prior to testing. He cautioned, however, that data-handling can be a problem since the nine-accelerometer method generates an "overwhelming" amount of data.

7. Ostelogic Studies for Determining the Skeletal Quality of Cadavers Used in Crash Testing, Michael Walsh, Calspan Corp.

Mr. Walsh reported on Calspan's continuing efforts to develop a method by which different researchers may compare cadaver condition. Bone strength is a good candidate because of the nature of biomechanics testing. The subject of cadaver comparability has been of interest to the workshop for several years and the present report summarized four techniques which may be useful in establishing bone strength comparisons.

The Granick and Stein rib test was first proposed to the workshop in 1975 and Calspan has been evaluating the technique since then. While it does provide a measure of comparability between cadavers, it is a rather complicated process which requires removal of a rib segment, differentiation between cortical and cancellous bone (difficult in practice), an elliptical approximation of rib cross-section to calculate moment of inertia, and a loading-to-failure test. Another major drawback is that the evaluation can only be performed post-test and thus cannot be used for pre-test selection of cadavers.

Another potential technique is the Epker and Frost rib test. This test is a parabolic index based on total rib cross-sectional area minus marrow area. The technique was introduced by Dr. Walsh at the 1976 Workshop. In application, it has been found to be indicative of osteoporosis and relatively insensitive to other variables. It's chief disadvantage is that the evaluation must still be performed post-test.

The radiologic long-bone test, another possibility, is based on work by Dr. Stanley Garn at the University of Michigan, who has radiologic studies of metacarpal bones of 2000 live subjects. He has successfully determined bone abnormalities using percent cortical area, and an assumed circular cross-section. This technique demonstrates male-female differences and osteoporosis.

The fourth technique, called-the radius test, has been developed and successfully used by Calspan. Calspan removes a thin mid-shaft section of the radius bone pre-test (occasionally the midshaft area is not available, in which case proximal or distal sections can be used in conjunction with correction factors developed by Calspan).. The proportion of cortical bone in the cross-section is determined and compared to the norms established by Dr. Garn. The technique was verified by applying Dr. Garn's approach to Calspan x-rays of femurs from previous tests. Calspan's data showed that cadavers which were successfully used as test subjects provided radius test results within one standard deviation of Dr. Garn's "normal" baseline. A major advantage of this method is that the cadaver can be categorized pre-test. Since the radius is used, test results will not be affected(unless the response of arm bones is a test objective).

Mr. Walsh point out that the Epker and Frost technique works well and is more effective than Granick and Stein, and only the Granick and Stein method requires loading. He also cautioned that the radius test did not necessarily infer that a cadaver scoring more than one standard deviation below normal was unsuitable for all tests. For example, cadavers that failed the radius test might be suitable for head testing but not for restraint system testing. Finally, he noted that osteoporitic individuals had low scores with all four categorization techniques.

Dr. Tarriere then commented briefly on bending and shearing tests his group had performed. He compared rib test results between cadavers of persons who had died of natural causes in old age and those of younger persons who had died in highway crashes while in otherwise good health. He found statistically different static and dynamic bending strengths and shear strengths between the two groups. He also determined the percentage by weight of mineral salts (residue after combustion) for various rib sections, and found large differences between the two groups.

8. Cadaver Post Classification, Dr. Rolf Eppinger, NHTSA.

Dr. Eppinger presented a "very preliminary" scheme to classify individual cadavers in relationship to the entire population at risk in traffic accidents as a means of assessing the applicability of test results. Dr. Eppinger developed his method based on percentage of fatalities as a function of age. Using a scaling relationship to account for weight, he developed a "normalized rib strength" (NRS) factor. When plotted against age, this factor shows the general decline in rib strength (as determined by the Granick and Stein test) with increasing age. To remove the age factor and create a method of comparing a given cadaver with the entire fatality population, he integrated the NRS/age curve and plotted "NRS as a percentile of fatality population "vs NRS." He will conduct further analysis with the technique to account for some of the statistical variance.

9. Alternate T-1 Coordinate System, Dr. Rolf Eppinger, NHTSA.

Some contractors lack the x-ray equipment necessary to establish the anatomical coordinate system at T-1 as recommended by this Workshop. Dr. Eppinger described an approach toward defining a T-1 anatomical coordinate system which could be established by easy, external, photographic means. The coordinate system he proposed would have its origin at the external protuberance of the T-1 spinous process and its x-axis through the top of the jugular notch of the sternum (suprasternale). Dr. Eppinger is checking this system against the T-1 system established with x-rays in hopes of finding a "cheap equivalent." He wants to define the variability between the systems so that contractors who cannot establish the x-ray-based system will still use an anatomical coordinate system which can be related to the x-ray system for comparison of test results.

Several attendees had comments and questions about this proposal. The first noted that most of the current methods use a two-dimensional x-ray to establish a three-dimensional coordinate system. This requires an x-ray or photo in the mid-sagittal plane. He wanted to know which landmarks would be used to define the coordinate system in a three-dimensional x-ray or photographic system. Dr. Eppinger said he wants to develop an accelerometer mount with orientation holes incorporated which would establish the coordinate system in each photograph. Another question referred to the reliability of T-1 as an external landmark. Dr. Eppinger acknowledged that T-1 is often difficult to identify positively, and that even neurosurgeons will choose either C-7 or T-1 when palpating. While noting that the only way to be absolutely sure is to have an x-ray available, he also mentioned that it is relatively unimportant whether T-1 was selected, so long as there is an internally consistent anatomical system which can be related to the external laboratory system. Anthropometrists and others agree that the first easily palpable spinous process is C-7, so Dr. Eppinger may recommend that the photographic coordinate system be established with C-7 as the origin. Last, Dr. Eppinger noted that a more specific method of establishing the x-axis will be needed, since the jugular notch of the sternum can "float" relative to C-7.

## INSTRUMENTATION

10. Current Status of Mouthpiece Accelerometer, E.F. Konigsberg, Konigsberg Industries.

Mr. Konigsberg presented a brief status report on the development of a miniaturized nine-accelerometer system with telemetering which is completely packaged in a boxer's mouthpiece. With reduced funding and new personnel on the project, only about four months of work were achieved during the year. However, accomplishments were made in three areas. Mouthpiece electronics - temperature sensitivity has been reduced to $\pm 0.5\%$ for the entire operating range. A demonstration system for the mouthpiece electronics was due to be ready by the end of calendar 1977. Accelerometers -- the natural frequency of the cantilever beam and fork beam has been measured at 2.7 - 3.3 $KH_z$, thereby achieving the design objective of $3KH_z$ center frequency. However, vibration tests have revealed that the beams do not perform in a "classic" manner. It is expected that changes in beam thickness and attachment by brazing will solve the problem. Microprocessor work in this area is directed at on-line computation at 600 usec intervals to accommodate the 800 Hz per channel sampling frequency capability.

11. Calibration for Rotational Accelerometer Devices, Dr. Stephen Gordon, Safety Research Laboratory.

A two-part calibration table has been developed to calibrate nine-accelerometer packages in rotation. The lower table is a commercially available genesco rate table with a capability of 500 rpm in the vertical axis of rotation. The upper table calibrates the horizontal axis of rotation at up to 600 rpm. The accelerometer test fixture is mounted between the motor and slip rings on the upper table. The product of lower table times upper table rotations cannot exceed 7250 rpm. The potential sources of calibration error have been identified as: 1) spin axes not perpendicular to one another; 2) spin axes which are perpendicular but do not intersect at a common origin; and 3) errors in speed and balance of the tables. The device produces a true angular acceleration - not a linear acceleration.

Dr. Gordon is now attempting to calibrate an Endevco nine-accelerometer system using the table. As of October, 1977, he had calibrated the system in two axes, but expected that remounting would be necessary for the third axis. Current plans for the device are to calibrate first the Endevco system, then the Konigsberg mouthpiece system. If it works accurately, the device may then be made available to NHTSA contractors and to others. However, each different accelerometer mount will require its own fixture for the calibrator. These currently cost about $1000.

12. Computation of Rigid Body Rotation in Three Dimensional Space from Body-Fixed Acceleration Measurements, Dr. Albert I. King, Wayne State University.

Dr. King validated a nine-accelerometer system using orientation of a rotation vector instead of Euler angles. These results were compared to three-dimensional film analysis results to establish a validation in the range of 5-7 g's. The nine-accelerometer system was found to be accurate for angular acceleration and velocity but not for displacement. A filter at 100 $H_z$ was found to have no effect on the calculations but made the techniques easier to visualize. Dr. King also checked a six-accelerometer system. In some cases, the calculations for a six-accelerometer system did not "blow up," but, in every case, departures from accurate results were found.

13. Angular Misalignment Errors in Mounting Linear Accelerometers to Anatomical Subjects, A. K. Johnson, NHTSA.

Mr. Johnson highlighted two potential sources of error when linear accelerometers are mounted in an array on a cadaver and are used to measure angular acceleration. He noted that the chief source of calibration error is due to misalignment of the accelerometer in its mount. The second source is related to difficulties in establishing the anatomical frame of reference and misalignment errors which occur when the accelerometers are located in the anatomical frame. He hoted that, as a practical matter, minor misalignment errors will have little effect on the angular acceleration readings obtained in the test. Mr. Johnson presented several conclusions and recommendations which are contained in his paper (included with these Proceedings).

14. Transforming Anatomically Acquired Finematic Parameters to Inertially Referenced Coordinates, Edward Becker, Naval Aeromedical Research Laboratory.

Mr. Becker briefly described the method used at NAMRL to transform acceleration data from the accelerometer reference system to the anatomical reference system and to process the data. A three-stage method is followed. 1) Using quaternious, the data are converted to time histories of direction cosiness and Euler angles. 2) These direction cosines and Euler angles are then transformed into the inertial reference system. 3) The transformed data are integrated to obtain translation and displacement results.

15. Validation of an Instrumentation Module Using Rate Gyros and Linear Accelerometers for Biomechanical Applications, Dr. Anthony S. Hu, Physical Science Laboratory, New Mexico State University.

Dr. Hu discussed the hardware arrangement used at PSL and the methods used to validate the system in two- and three- dimensional modes. The acceleration-measuring module consists of three Hamilton Standard Series 54 rate gyros and three Endevco 2264 accelerometers. The rate gyros are off-the-shelf items, 1.5 inches high x 1 inch diameter, weight 3 ounces, response range $\pm$ 5000 degrees/sec. The overall package size for the module is 1.5 x 2.5 x 3.5 inches, and it weighs 12 ounces. Two-dimensional validation tests were performed with the accelerometer module placed at the center-of-gravity of a pendulum-mounted headform. Angular velocity was measured, then integrated to calculate displacement and smoothed and differentiated to calculate acceleration. These results were compared to data from high-speed motion pictures. Displacement data were measured from the film, then smoothed and successively differentiated to calculate velocity and acceleration.

The same basic arrangement was used to validate the three-dimensional model, except that the accelerometer module was offset with respect to the "anatomical" plane of the headform (up 20°, right 45°). A planar test was conducted, and the results were transformed to the anatomical plane using direction cosines. A further transformation to the laboratory coordinate system was achieved using a direction cosine matrix for the accelerometer data and a recursive formula for the rate gyros. These results were again compared to filmed data. Dr. Hu concluded that good validations were achieved for both displacement and velocity (both angular and linear components). However,angular acceleration did not validate as well as hoped, and linear acceleration was not as well-validated as angular acceleration.

Since the module weighs 12 ounces, two tests were conducted to determine weight effects on kinematic response by adding a one-pound weight to one side of the headform pendulum. Very slight differences were noted between the results with and without the weight. Responding to a question about his smoothing technique, Dr. Hu said that he used at least-squares 4th order method for each adjacent five points.

16. Measurement of 3-D Motion, Dr. Nabih Alem, HSRI.

Dr. Alem is developing methods to analyze digital data from HSRI's head-mounted nine-accelerometer system. The system consists of three triaxial accelerometers mounted orthogonally at three widely spaced points on the skull. An orthogonal jig is used to align the accelerometers which are rigidly mounted to the skull with dental acrylic. The maximum spacing is used to increase the distance between accelerometers and the accuracy of the measurements.

Dr. Alem's experience with processing the data from this system has led him to propose several guidelines for filtering digital data for rigid body motion analysis. He has found that the Class 1000 filters prescribed in SAE J211 data processing guidlines (which were developed for dummy testing) are of too high a frequency for cadaver head response testing. He proposes that, for direct impacts to cadaver heads, a 400 $H_z$ filter be used for rigid body analysis. If the cadaver head is not directly impacted, rigid body analysis should be performed after filtering to 200 Hz.

Dr. Alem noted that many guidelines exist for processing of analog signals, but when those signals have been converted to digital data, there are no processing guidelines. Guidelines are needed for analog-to-digital conversion filters and for digital filtering. HSRI feels that the SAE J211b guidelines do not include enough attention for the A-D conversion, and recommends 24 db attenvation for the Nyguist rate. For digital filtering, HSRI feels that linear phase analog and digital filters should be used and that recommended filter specifications should be adopted for passband, stopbared and transition frequencies.

Dr. Melvin then noted that the lack of filtering guidelines is another aspect of cadaver testing which leads to noncomparability. The Workshop agreed that a special ad-hoc subcommittee was needed to address the problem. The subcommittee was duly established, with the following members: N. Alem of HSRI, C. Ward of Naval CEL, A. Hu of PSL, A. King of Wayne State University, Y. K. Liu of Tulane, R. Hubbard of Michigan State University and a member of the GM Research Labs to be named later.

17. Instrumentation for Measuring In-Vitro Three-Dimensional Relative Motion of Intervertebral Joints, Prof. A. H. Soni, Department of Mechanical and Aeronautical Engineering, Oklahoma State University.

Problems of knee injury in sports and spinal scoliosis have lead to Profess Soni's recent efforts to study joints of the body under three-dimensional conditions of normal motion and loads. He is attempting to develop both kenematic measurement and data processing techniques. A linkage transducer developed at Stanford and consisting of six links and six potentiometer transducers has been used at Oklahoma State to produce accurate data in low-speed fatigue tests of knees. Prof. Soni's group is now trying to adapt this linkage transducer concept to studies of the spine. His method is to use a staggered arrangement of links clamped over vertebrae spinus processes, but he is finding that potentiometers are too large for the severe space limitations. The other problems with potentiometer transducers are that they measure only displacement and provide only static measures. The linkage system approach is based on the theory of instantaneous kinematics applied to the measurement of relative motion of surfaces. Dr. Soni closed by asking for suggestions for appropriate instrumentation and the use of the linkage transducer.

Following this paper, the Technical Session was completed. Mr. Hirsch expressed his appreciation to those who had contributed presentations to the Workshop and to those who had attended. The Workshop was concluded at 5:30 p.m.

David R. Foust
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Secretary's address

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